Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 48 (2014) 1236 – 1243

Energy Procedia

SHC 2013, International Conference on Solar Heating and Cooling for Buildings and Industry
September 23-25, 2013, Freiburg, Germany

From solar building design to Net Zero Energy Buildings: performance insights of an office building

Laura Aelenei[a]* and Helder Gonçalves[a]

[a]*Laboratório Nacional de Energia e Geologia (LNEG), Paço do Lumiar 22, 1649-038, Lisbon, Portugal*

Abstract

Net Zero-Energy Buildings Performance has gained more attention since the publication in 2010 of the EPBD recast [1]. Successful implementation of such an ambitious target depends on a great variety of factors. With a literature full of theoretical advice and a building industry rife with myths about the value of technologies, the present study intend to unveil an sustainable framework for sharing insights into NetZEB methodology applied in an Portuguese office building, Solar XXI, based on the authors experience in the ongoing research carried out within International Energy Agency SHC Task 40 - ECBCS Annex 52, "Towards Net Zero Energy Solar Buildings”

Selection and peer review by the scientific conference committee of SHC 2013 under responsibility of PSE AG

Keywords: Solar building; renewable energies; zero energy buildings

1. Introduction

Zero Energy performance buildings have gained more attention since the publication in 2010 of the EPBD recast [1]. Meanwhile the USA promotes “marketable zero energy homes in 2020 and commercial zero energy buildings in 2025” [2]. Japan proposes “carbon neutralized buildings”, including existing buildings, by 2050 [3]. The UK government aspires to achieve a zero carbon standard by 2016 [4]. With countries well on the way to putting this new standard into effect, worldwide around three hundred buildings are already claiming Zero Energy or similar

* Corresponding author. Tel.: +351 210 924 600.
E-mail address: laura.aelenei@lneg.pt

1876-6102
Selection and peer review by the scientific conference committee of SHC 2013 under responsibility of PSE AG
doi:10.1016/j.egypro.2014.02.140

performance [5]. Successful implementation of such an ambitious target depends on a great variety of factors. For designers and code writers these include: balancing climate driven-demand for space cooling with climate-driven supply for renewable energy resources and/or matching building design to shade from the sun in summer while providing for good daylight. With a literature full of theoretical advice and a building industry rife with myths about the value of technologies, the study of this new concept may be decisive in establishing the best strategies for achieving true Net Zero energy performance.

Although there is no exact approach for designing and realizing a net-zero energy building (there are many different possible combination of building envelope, utility equipment and on-site energy production equipment able to achieve net-zero energy performance) there is some consensus that zero energy buildings design should start from solar passive sustainable design [6, 7]. According to this, the net zero-energy performance may be achieved as a result of executing two fundamental steps: (a) reduce building energy demand - energy efficiency and (b) generate electricity or other energy carriers, to get enough credits to achieve the desired energy balance - energy generating.

Passive approaches play a fundamental role in addressing NetZEB design as they affect directly the loads put on the buildings mechanical and electrical systems, and indirectly the strive for renewable energy generation. In general, in heating and cooling dominated climates, the passive heating solutions must be studied together with the cooling solutions in order to avoid undesired overheating and glaring by daylight. Passive cooling are pursued mainly by increasing building time constant through thermal inertia increasing, to allow a significant building cooling load reduction while the benefits of natural ventilation and day lighting are explored. On the other hand, in cooling dominated climates characterized by a high potential for natural ventilation, wall insulation should be avoided to allow an easier cooling of the house during the night (something that the insulation will prevent). Generally, the design of passive solutions of NetZEB´s may be a challenging task given the constraints related to desired energy performance level/CO2 emission reduction target, climate, type of building, etc. Although the main principles applied in solar passive sustainable design are well known, the fundamental issue here is to find if the same can be applied in NetZEB as well. The authors of this paper, who are active participants in the IEA Task 40/Annex 52 ("Towards Net Zero Energy Solar Buildings") [8] intend to present and discuss the strategies used for heating and cooling of a nearly Zero Energy solar Building, Solar XXI, project that integrates the IEA database of about 200 nearly zero, net zero or positive energy buildings, with the aim of defining solution sets and indicators of relative performance. Solar Building XXI, built in 2006 [9], at LNEG Campus in Lisbon, pretends to be an example of a solar low energy building using passive systems both for heating and cooling (ground cooling) towards a Net Zero-Energy Building (NZEB) [10]. The main façade has a PV system with heat recovery which assists the heating in winter time. In summer a ground cooling system (earth tubes) is used to cool the building, together with night cooling strategies. The overall informations about the building are summarized in Table 1.

Nomenclature

EPBD	Energy Performance Buildings Directive
NetZEB	Net Zero Energy Buildings
IEA	International Energy Agency
BIPV-T	Building Integrated Photovoltaic – Thermal
$f_{load,I}$	Load match index

2. From solar building design to zero energy buildings

Net Zero Energy Building (NetZEB) concept may be defined as a building that over a year is neutral (i.e., it delivers as much energy to the supply grids as it uses from the grids) when energy efficiency measures are successfully combined with energy renewable sources. According to this, the net zero-energy performance may be achieved as a result of executing two fundamental steps: first reduce building energy demand, and second, generate electricity or other energy carriers, to get enough credits to achieve the desired energy balance. In the first step passive approaches play a fundamental role in addressing NetZEB design, as they affect directly the loads put on the buildings mechanical and electrical systems, and indirectly the strive for renewable energy generation.

Table 1. SOLAR XXI Building - Renewable Energy Systems data.

General informations	Productivity (*kWh/kW*)
Location	Lisbon Latitude 38°46'20.27" north Longitude 9°10'39.83" west
Owner	National Energy and Geology Laboratory (LNEG)
Project co-ordinator	Helder Gonçalves helder.goncalves@lneg.pt
Building costs (tax included)	800 €/m2
Typology	Office building
Climate data	Temperate Heating period 5.3 month Heating Degree Days 1190ºC (Tb 20ºC)
Main stimulation of the project	Test, experimental, research
Building construction	High
Number of occupants	20 pc
Heated net floor area	1200m^2
Gross floor area	1500 m^2

2.1. Energy efficiency comes first - solar building design

Passive solar design takes advantage of a building's site, climate, and materials to minimize energy use. A well-designed passive solar building first reduces heating and cooling loads through energy-efficiency strategies and then meets those reduced loads in whole or part with solar energy. With respect of Solar XXI building, its design performs both steps. Firstly, it includes a large number of energy efficiency measures and strategies adopted in order to reduce the heating, cooling and lightning loads. In the case of Solar XXI, the solar design of the building integrates a number of measures as:

- Use of solar gains

The main building façade (South oriented) is covered by windows and PV modules by equivalent proportions. This large glazing area (about 46% of the south façade and 12% of building conditioned floor area) interact directly with the office rooms permanently occupied, collecting direct solar energy, providing heat and natural light to these spaces. Increasing the solar heat gains in winter time consisted one of the dominant strategies in the building design, by adopting essential features such as location, size and orientation (south) of the main glazing area (Fig. 1).

Fig. 1. SolarXXI building (interior and exterior views).

- Building Integrated Photovoltaic - Thermal (BIPV-T)

In addition to the use of direct solar gains through the windows, the BIPV-T system integrating south building façade is also contributing for the improvement of the indoor climate during heating season in the day time hours, when the heat released in the process of converting solar radiation into power is successfully recovered (Fig. 2). As a heating strategy, in winter time during the days with high solar radiation, the temperature of the air heated by BIPV-T and insufflated into the offices can rich 30ºC [10].

- Natural lighting e natural ventilation

The location and dimension of central skylight as a main light distributor in the central hall is fundamental, as also the translucide vents in the doors which communicate from south and north spaces to corridor and the glazing areas distributed all over the building envelope. These important features adopted in the building design led to a reduction of the electric light building consumption. Natural ventilation is provided due to cross wind and stack effect via openings in the façade and roof level. The façade openings together with adjustable vents on all office room doors provide the cross ventilation, allowing the air to flow from inside to outside and vice versa. In the building central hall there is a skylight, which allows for natural ventilation by stack effect (Fig. 1).

In the same time the SolarXXI design integrates cooling measures for lowering the building consumption in cooling period:

- Windows shading

Venetian blinds adjustable by the users were placed outside the glazing to limit direct solar gains. When applied externally, become a very important measure for summer period, since they minimize the direct solar incidence.

- Ground Cooling System

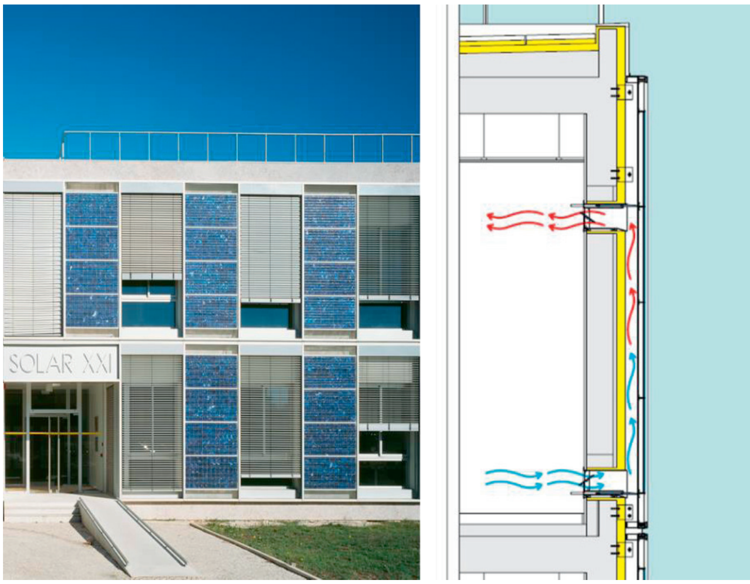

Fig. 2. SolarXXI building BIPV-T system.

A ground cooling system provides incoming pre-cooled air into the building using the earth as a cooling source. The system consists of 32 tubes with 30 cm diameter, buried at 4.5 m depth (Fig. 2). The ground temperature varies from 13 to 19 ºC throughout the year, so it represents an excellent cooling source during summer season. The air enters into the tubes array 15 m away from the building, cross the tubes circuit cooling to a temperature near the ground and is injected into the building office rooms by natural convection or forced convection using small fans. The system operates with great efficiency in the hot summer days, when the indoor temperature is significantly higher, by pushing the fresh air from the buried pipes. The air temperature injected inside the office rooms ranges between 22-23 ºC, resulting in a decrease of the indoor air temperature between 2 and 3 ºC.

2.2. Second step - energy generation

The integration of renewable energy systems in the Solar XXI design was one of the main objectives of the project. The building integrates on his façade and nearby (car parking) 3 PV systems that supply all the electric demands of the building with a total installed peak power of about 30kW, and a Thermal Solar Collectors used for heating purpose. The SOLAR XXI building Renewable Systems are summarized in Table 2.

Table 2. SOLAR XXI Building - Renewable Energy Systems data.

Renewable Energy Systems	Integration	Area (m^2)	Installed pick power(kW)	Productivity (kWh/kW)
76 PV multicristalline silicon	Building façade	96	12	1004
100 PV amorphous silicon	Car parking 1	95	6	1401
150 PV CIS thin-film	Car parking 2	110	12	1401
CPC solar thermal	Building roof	16	11 MWh	

As suggested in literature [11], a relevant indicator in the building energy generation and NetZEB topic is the so called load match index - solar fraction describing the ratio of the PV yield to the load. Addressing the load match creates the need to detail the energy flows on the season level, month, week, day, hours depending on the level of accuracy and data availability.

All generated power exceeding the load is considered as part of the grid electricity, so that the maximum load match index becomes 1 or 100%. As the index strongly reflects the time resolution considered, the time interval must be part of the index name. With increasing time interval, excess production decreases. The annually based load match index of a Net is per definition equal to 1. Load match indices based on higher resolution data are averaged to an annual value, keeping the resolution indicator [11]:

$$f_{load,\,i} = \min\left[1,\ \frac{\text{on site generation}}{\text{load}}\right] \text{ x } 100\ [\%] \tag{1}$$

where .i = time interval (h, w, m)

Fig. 3 illustrates the load match index in the resolution of months, weeks and hours for the SOLAR XXI building together with the annual averages. Monthly and daily resolutions result in similar annual average load matches, whereas the hourly resolution leads to much lower values, due to the missing PV yield during night.

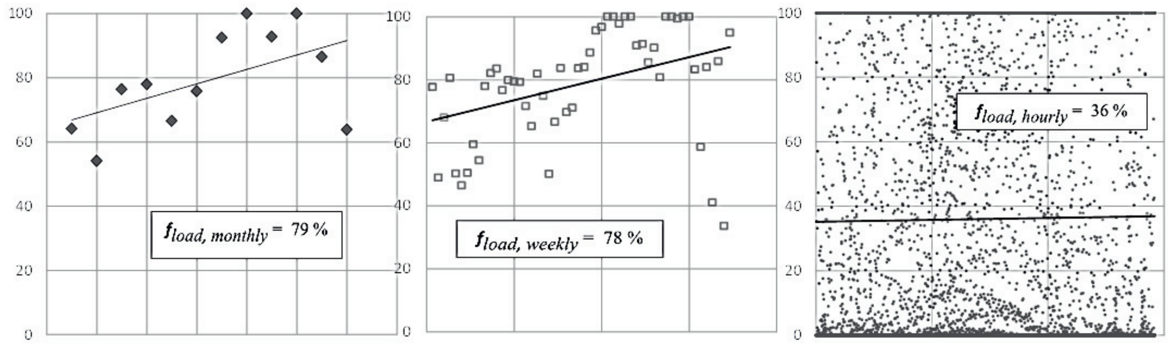

Fig. 3. SolarXXI - Load match index.

The last monitoring analysis performed has shown a total amount of electric energy consumption of 36 MWh, versus an amount of electricity produced by the three PV systems of the almost 38 MWh. In Fig. 4 is presented the monthly distribution of the electric energy consumed by Solar XXI versus the energy supplied by the PV system (façade + parking) for the 2011.

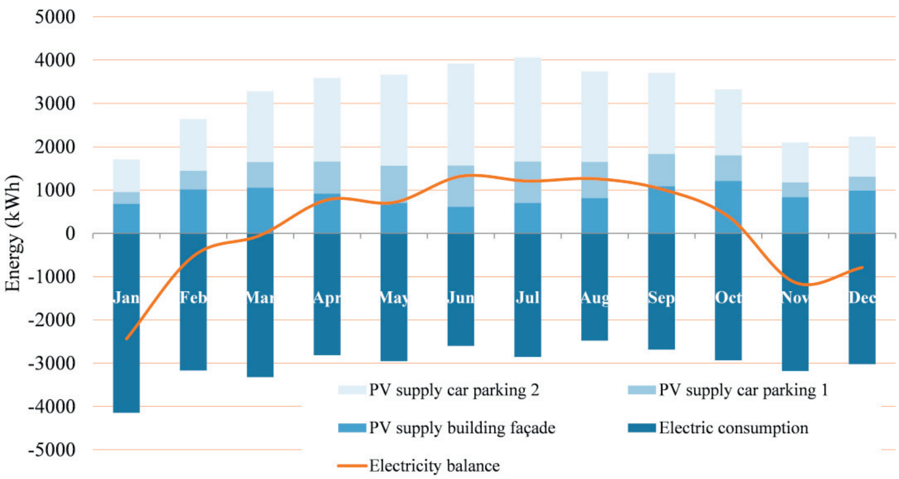

Fig. 4. Solar XXI - monthly electric energy consumption/PV (façade + parking) energy supply.

3. SolarXXI building – (nearly) zero energy building

As it has been described above, the Solar XXI integrates efficient solution sets and strategies, from the features reducing building energy demands, to integration of the renewable energies. As it has been described above, the Solar XXI integrates efficient solution sets and strategies, from the features reducing building energy demands, to integration of the renewable energies. Fig. 5 shows the Solar XXI performance from an energy balance approach perspective versus the critical steps towards NetZEB performance.

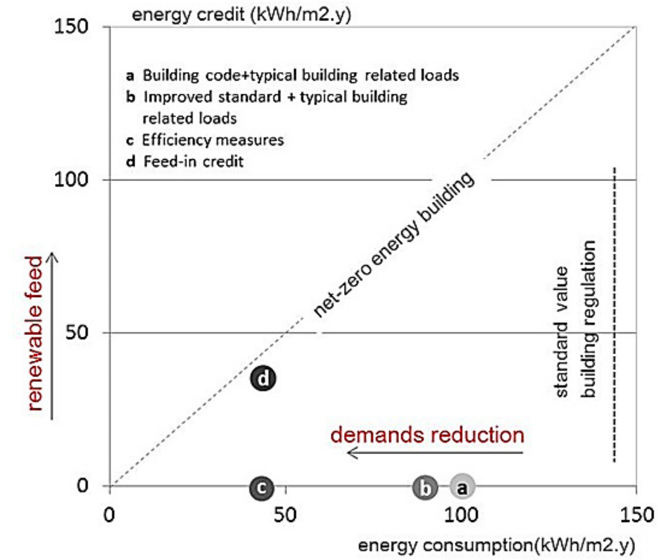

Fig. 5. SOLAR XXI - the path to net zero-energy performance [12].

If designed as a standard office building in accordance with the current Portuguese Building Code, Solar XXI would consume approximately 101kWh/m2.y including typical user related loads (a). If one would have performed improvements at level of the building envelope (and still continue with typical user related loads), the building would have consumed 90kWh/m2.y (b). On the basis of the improved building envelope and the outlined passive techniques and strategies, Solar XXI building annual energy consumption is 43 kWh/m2.y (c). This consumption is offset with a credit of 35.85 kWh/m2.y energy generated by the photovoltaics and solar thermal collectors (d), thus, the final balance of the building points out a near zero-energy performance.

4. Final remarks

With this paper the authors were able to share the main findings of the research carried in the design process of an office building currently underway to reach NZEB performance. Along the lines of the paper it has been shown the road traversed by Solar XXI on its way towards reaching zero-energy performance objective. It is believed that the set of solutions adopted, especially based on solar passive design, the daylighting performance characteristics, the natural ventilation strategies, the passive heating and cooling techniques, together with the integrated renewable energy systems, qualifies the Solar XXI building for exemplary energy performance. Solar XXI building energy performance is about ten times the energy performance of a standard new office building in Portugal [13]. Looking at the energy balance of the building from a NetZEB perspective, it was shown that the wise combination of standard and innovative energy performance measures with renewable systems is able to achieve the zero-energy performance without significant efforts. The authors of this work are hoping that the lessons learned during design, construction and operation of the building will provide useful clues to all interested in developing outstanding energy projects in Southern European countries and not only. At the same time it is also important that this work help policy makers and stakeholders identify (and counteract) the barriers against broader implementation of NetZEB´s.

References

[1] The Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union.
[2] DOE, Building Technologies Program, 2008 http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/myp08complete.pdf.
[3] Yokoo N. Transition of Technology and Belief for Green Buildings in Japan, International Conference on Sustainable Integrated Design Process for Building and Construction, Hong Kong, 2009.
[4] Department for Communities and Local Government, Sustainable New Homes – The Road to Zero Carbon: Consultation on the Code for Sustainable Homes and the Energy Efficiency standard for Zero Carbon Homes, London: Department for Communities and Local, 2009.
[5] Musall E, Weiss T, Lenoir A, Voss K, Garde F, Donn M. Net Zero energy solar buildings: an overview and analysis on worldwide building projects, EuroSun conference, Graz, Austria, 2010.
[6] Aelenei L, Lollini R, Gonçalves H, Aelenei D, Noguchi M, Donn M, Garde F. Passive cooling approaches in Net-Zero Energy Solar Buildings: lessons learned from demonstration buildings, CISBAT2011 Conference, Lausanne, 2011.
[7] Sartori I, Napolitano A, Marszal AJ, Pless S, Torcellini P, Voss K. Criteria for Definition of Net Zero Energy Buildings, EuroSun conference 2010, Graz, Austria, 2010.
[8] The IEA SHC Task 40 / ECBCS Annex 52 'Towards Net Zero Energy Solar Buildings (NZEBs); http://www.iea-shc.org/task40/index.html
[9] Gonçalves H, Cabrita P. A Passive Solar Office Building in Portugal. PLEA Conference, 2006.
[10] Gonçalves H, Camelo S, Horta C, Graça JM, Aelenei L, Oliveira MP, Joyce A, Rodrigues C. Solar XXI-Em direcção à energia zero / Towards zero energy, @LNEG 2010 (IBSN:978-989-675-007-7). Lisbon; 2010.
[11] Voss K, Sartori I, Napolitano A, Geher S, Gonçalves H, Hall M, Heiselberg P, Widén J, Candanedo JA, MusallE, Karlsson B, Torcellini P. Load Matching and Grid Intercation of Net Zero Energy Buildings. EuroSun conference 2010, Graz, Austria, 2010
[12] Gonçalves H, Aelenei L, Rodrigues C. SOLAR XXI: A Portuguese Office Building towards Net Zero-Energy Building. REHVA Journal 2012; 3: 34-40.
[13] Aelenei L, Gonçalves H, Rodrigues C. The Road Towards "Zero Energy" in Buildings: Lessons Learned from SOLARXXI Building in Portugal, Proceedings of EuroSun 2010, Gratz, Austria, 2010